p-12

CSD

COMPUTER SERVICES DIVISION

Computers in Aeronautics and Space Research at the Lewis Research Center

NASA

Cover photograph:

S-shaped duct displayed on Iris workstation.

Introduction

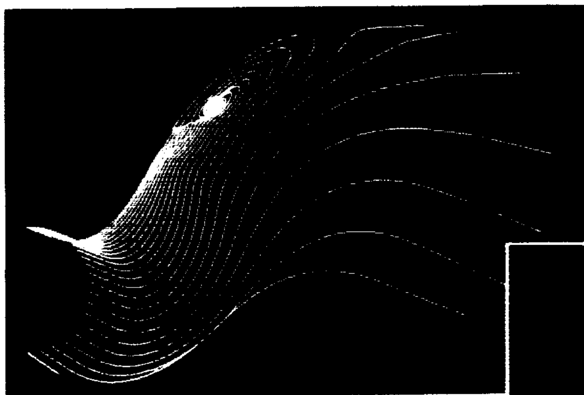
The Lewis Research Center's mission as stated in its Center charter is to meet the Nation's aeronautics and space needs through "research and technology development in aeropropulsion, space propulsion, space power, microgravity science, and communications."

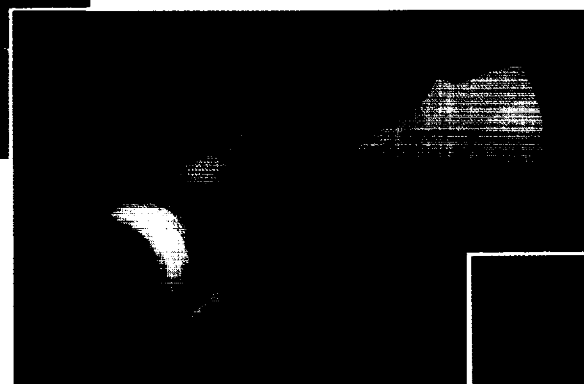
The challenges in aeronautics and space research are many. Looking for answers and solving problems related to propulsion and power systems has put Lewis in a position of leadership in these areas. Lewis has made major advances leading to the development of the advanced turboprop engine, which greatly increases aircraft fuel efficiency, as well as in supersonic short-takeoff, vertical-landing (STOVL) aircraft propulsion and in aircraft icing research. Lewis continues to make advances toward the development of an engine for orbital transfer vehicles, in thrusters for maneuvering spacecraft, and in heat transfer and cooling for rocket engines. NASA's Advanced Communications Technology Satellite, solar energy research, battery life-cycle experiments, and the power system for Space Station *Freedom* are only some of the other research projects in which Lewis is involved.

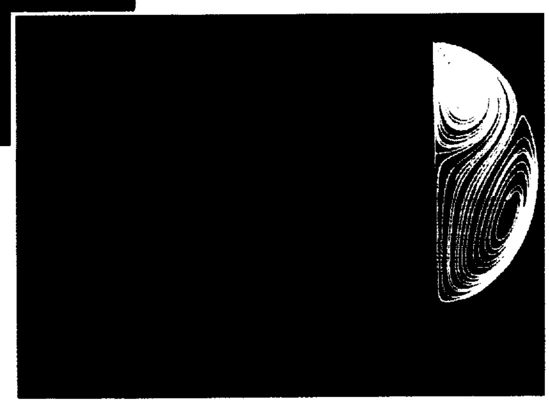
Computers have come to play a major role in all scientific research. In fact, many of the research methods used today rely on computers. The computer's ability to perform hundreds of thousands or, in some cases, millions of calculations per second has made some projects feasible that would have been impossible in the past due to time and cost constraints.

This brochure tells how computers are used in research at Lewis. The focus is on four general areas; computer modeling and simulation, computer-assisted engineering, data acquisition and analysis, and computer-controlled testing. It is not a comprehensive overview; with so much work currently being done at Lewis, not every project could be covered. Instead, the brochure shows just some of the ways computers are applied to aeronautics and space research.

Computer Modeling and Simulation







Three views of an S-shaped duct as displayed on an Iris workstation. (Top) Subsonic particle flow over the inside surface. (Middle) Pressure on the inside surface. Blue indicates high pressure; red indicates low pressure. (Bottom) A simulated end-on view.

Before today's high-speed computers, advancement in aeronautics and aerospace design was slowed by the necessity to build, test, and evaluate every new design and every design modification. Ideas that looked good on paper often failed to stand up to the stresses, pressures, and temperature changes that they met in the real world. Although building and testing prototypes is still a necessary step in proving a design, computers have made available new methods that greatly enhance a designer's ability to build prototypes that will succeed the first time.

Using computer logic, mathematics, and experimentally proven scientific knowledge, researchers are able to model and simulate objects and processes on a computer. The way air particles behave as they move over the surfaces of a jet engine's turbine blades, for example, can be described in terms of a computer program. The program can then be run, analyzed, and modified to help answer critical design questions. How will the particles behave at different speeds? What will be the effect of varying temperatures? How might other air particles be affected? Generally speaking, research scientists use two kinds of computer modeling techniques. One is called geometric modeling or solids modeling. It concentrates on describing objects, such as the jet engine turbine blades referred to in the preceding example. The other technique is called physics modeling. It concentrates on describing processes, such as tracing airflow.

Researchers can choose to observe their models from different points of view depending on what they want to see. For example, one point of view may focus on following a particular particle of air as it passes through a jet engine. It allows researchers to observe the travel of the particle all along its path. This point of view is similar to that of a person in a boat following a particular leaf as it floats down a stream. Another modeler may need to take a fixed point of view to observe the flow of many air particles through the engine. This fixed point of view would be like watching from the shore as thousands of leaves float by.

The design process always begins with a requirement, such as the need for a more fuel-efficient turboprop. To meet the requirements of fuel efficiency, a propeller must be designed to produce a certain amount of thrust when coupled with an engine of a given horsepower. In their role as computer modelers, scientists and engineers must describe thrust as a set of equations. Thousands of variables that affect the stress and strain on the propeller also must be accounted for. Using all these factors as input, the computer solves the equations in order to model the propeller design.

Through computer modeling and simulation, research engineers get more detailed information about the designs they are testing. And because a prototype does not have to be built

CSD

Artist's concept of National Aerospace Plane.

for each variation, experimental facilities have more time for testing existing prototype models. The combination of highly detailed results and more testing ultimately leads to better designs.

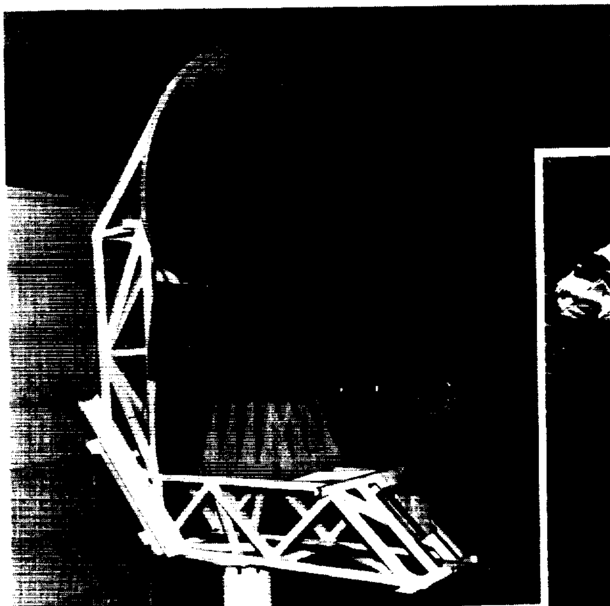
Researchers in the Aeronautics Directorate at Lewis are applying computer modeling and simulation techniques to the development of the National Aerospace Plane (NASP). This spacecraft will be the first to take off from a runway like a conventional aircraft, travel into space, reenter the atmosphere, and land on a runway. Because the speeds that the NASP is being designed to attain far exceed any wind tunnel's capacity, computer modeling and simulation techniques are being relied on to provide high-speed test data. These kinds of simulations require an enormous amount of computing power. So many calculations must be made that one such simulation might take hours to run on an average computer. Lewis' Cray supercomputer, built by Cray Research, Inc., greatly shortens the run time. Researchers also use one of Lewis' several VAX clusters for running simulations. These groups of individual VAX computers, built by the Digital Equipment Corporation, are specially configured to provide more efficient processing.

Computers such as the Cray and the VAX are ideal for running simulations but are not always the best choice for displaying results. To do this, researchers are using advanced graphics workstations, such as the Iris, built by Silicon Graphics Corporation. These kinds of systems, similar to personal computers but much more powerful, can display graphic results of simulations and models in as many as 16 million colors in two or three dimensions.

Graphics animation can be used to produce color displays that help engineers find such conditions as undesirable vibrations. Such a model might perform a three-dimensional analysis of airflow as it passes through the inlets of an advanced jet engine, into its internal ducting, and out its exhaust nozzles. Simulations of chemical changes inside a jet's combustion chamber can be displayed in various colors to help researchers make predictions about the chamber's durability.

Data Acquisition and Analysis

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



Antenna Test Facility.

When researchers design experiments, they often plan to have computers monitor and record the results. Special systems that can receive, display, and store input from devices such as strain gages and pressure sensors have been developed at Lewis. These data acquisition systems are designed to gather experimental data, display them in an understandable format, and store them for later analysis. Lewis specialists have developed data acquisition and processing systems, such as TRADAR and Escort, to meet the special needs of the research scientist.

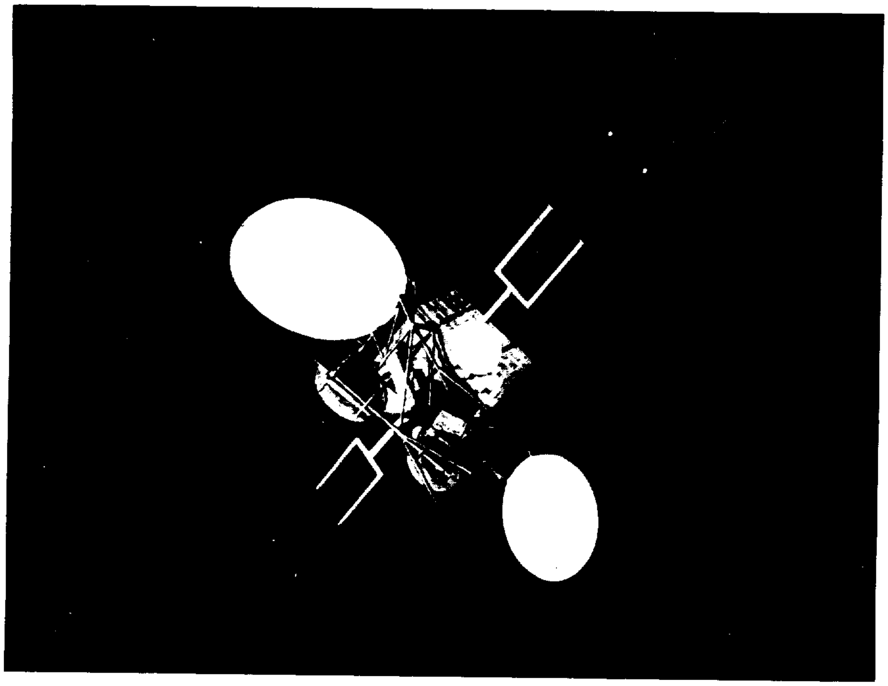
Planning an experiment usually requires the support of scientific programmers, data acquisition specialists, and design engineers. Details on how data are to be gathered, stored, and displayed during an experiment must be worked out before the experiment can be set up. For example, when a jet engine turbine blade is tested in a wind tunnel, the right instruments must be selected to measure temperature, pressure, and stress on the blade. The instruments, in turn, must be coupled with the right data acquisition system for the job.

The Transient Data Acquisition and Recording (TRADAR) system gathers and records events that change rapidly. During the firing of an engine scientists may have only 5 seconds in which to get the information they need. In that small slice of time they must acquire as many readings as possible. Sometimes researchers using TRADAR acquire more data in minutes than they can analyze in months.

Escort is a data acquisition system used to monitor more slowly changing processes, such as gradual changes in temperature or pressure measured by a strain gage. As data flow into Escort's microcomputer, a "snapshot" or instant recording of all instrument readings can be taken and saved electronically for later analysis.

The introduction of the highly portable microcomputer into the data acquisition process means that researchers have the option of gathering data on site. Not having to transmit data over a communications network to another computer gives the scientists running the experiment greater local control over their tests.

Because full assembly and testing on Earth might overstress its components, researchers in the Space Station Directorate at Lewis use computers to test Space Station *Freedom's* electrical distribution system. The job of the computer-



Artist's concept of ACTS.

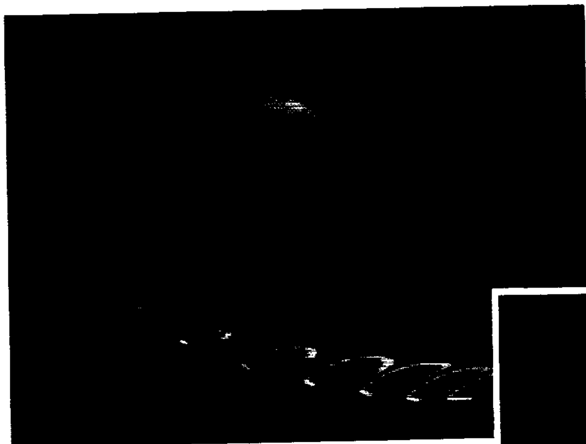
controlled distribution system is to make the most efficient use of onboard electric power consumption. Subsystems, including life support, heat, oxygen, humidity, refrigeration, pressure, communications, lighting, and even the small gas-powered resistojets that are responsible for maneuvering the space station, will all depend on energy collected by its solar arrays and stored in batteries. In the Space Power Research Laboratory, Lewis researchers conduct life-cycle experiments on nickel-hydrogen battery cells to be used aboard Space Station *Freedom*. As many as 40 battery cells are repeatedly charged and discharged. Life-cycle testing requires the system to run continuously. It may not be shut down even when new batteries are added or old batteries taken off. Data acquisition and management are complicated even further by all 40 batteries switching and cycling at different times. Escort is able to simultaneously scan all the batteries every 2 or 3 seconds and read current, voltage, temperature, and pressure transducers. Escort then separates and records the data for each battery cell. Data are transmitted through special cables to the VAX cluster for analysis.

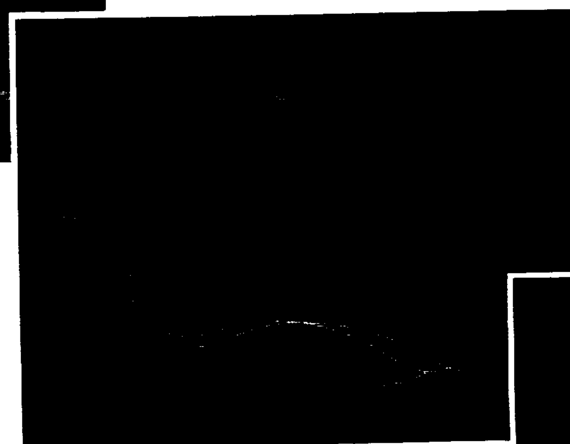
Researchers in the Antenna Test Facility perform experiments that support the Advanced Communications Technology Satellite (ACTS) project and advanced antenna designs. One experiment uses a 3-meter-diameter dish antenna to broadcast radio signals inside an anechoic chamber—a test cell made of materials that absorb radio waves. A second, much smaller receiving antenna (probe) is set up to measure output from the dish. The space between the two antennas can range from only a few inches to a few feet. Because of the importance of positioning the receiving antenna accurately, a computer-controlled laser measurement system is used. As the computer controls the movement of the receiving antenna, data about the magnitude and phase of the broadcast field are recorded. With these "near field" measurements researchers can use the VAX cluster to predict how the far-field pattern will look when the signal is broadcast from a satellite 22,000 miles away. It takes the VAX only a few minutes to calculate the characteristics of the far field from the near-field data. These calculations are so intensive that before the appearance of high-speed processors a research center like Lewis would not have been able to perform an experiment like this at all.

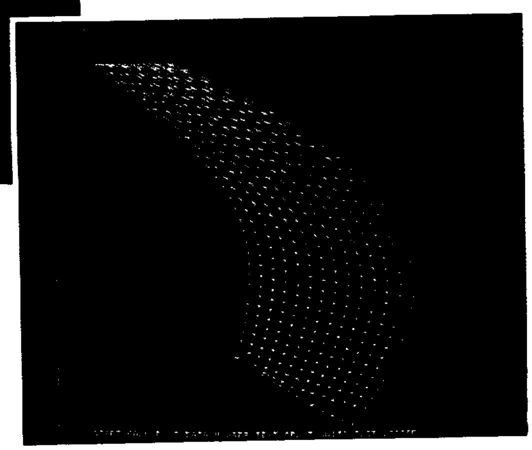
The central analog system is a frequency-modulated (FM) recording device for high-frequency data acquisition. Located in the Research Analysis Center, the central analog system is connected to numerous test facilities across the Center by specially shielded data cables. The system can record about 16 minutes of high-frequency data on FM tape at a rate of 120 inches per second.

Once the data have been recorded on FM tape, they can be sent to the analog-to-digital conversion system to be analyzed by a computer. If the data do not require computer analysis, they can be played back and displayed as strip charts or observed by means of an oscillograph or spectrum analyzer.

Computer-Assisted Engineering







Advanced turboprop blade. (Top) Leading-edge vortex imaged with particle traces. (Middle) Leading-edge vortex imaged by using density. (Bottom) Finite element model in which blade is divided into sections.

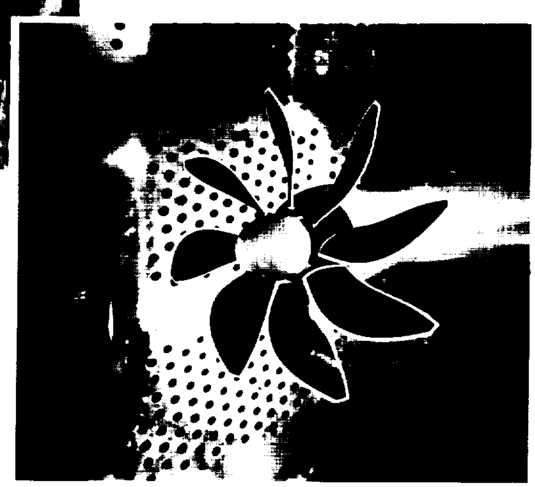
More than ever, researchers at Lewis are using computers in meeting national aeropropulsion and space propulsion needs. New ideas are worked into designs with computer-aided design (CAD) programs. Engineering analysis programs are used for testing and evaluating designs. Prototypes are manufactured for wind tunnel testing with programs such as Computer-Assisted Design and Manufacturing (CADAM).

CAD systems have almost completely replaced the drawing table at Lewis. Design work can be completed faster and more accurately with the help of computers. Changes that used to necessitate complete redrawing can now be made with a few keystrokes. Designs can be made to appear as three-dimensional geometric outlines and can be rotated for different views or zoomed-in on for closeups.

The design process begins with a design objective or problem. Design requirements are discussed and a general idea of how to approach the problem is arrived at. Once the requirements are understood, the designers may begin with something as simple as a hand sketch. The next step is describing a geometric model. Here, CAD programs can be used to help develop the actual design.

Once a geometric model has been described with CAD, it can be tested by using computer-assisted engineering analysis programs. With these programs researchers can determine whether a geometric model is workable by subjecting it to the simulated effects of stress, heat, and pressure. One way that this can be accomplished is by instructing the computer to divide the geometric model into basic shapes such as cubes, cylinders, and pyramids and then subjecting these basic shapes to rigorous tests that simulate the kinds of forces the design would be expected to meet. By using this method and the Cray and VAX computers, Lewis researchers are able to find weaknesses in their designs. The results of such analyses might require reworking the model and making design changes with CAD programs.

The designers continue to analyze their model until they have enough confidence in the design to build a working prototype for testing. This interaction between CAD modeling and design analysis can continue through many versions of the design. But at some point the analysis stops and a prototype has to be manufactured and tested. When to stop testing and redesigning is a decision that must be based on years of engineering experience.



(Middle) Machining operations. Advanced turboprop blade mold being cut. (Bottom) Single-rotating turboprop model in 8- by 6-Foot Wind Tunnel test section.

When the geometric model is complete, it may be sent to the computer-aided manufacturing (CAM) area, where a mold can be machined. Because CAD describes the design as a three-dimensional geometric model, the machine tool operator does not have to work from a set of drawings to manufacture it. Instead, the operator can load the model into a computer-controlled cutter and shape a mold of the part automatically. The finished part can then, for example, be put into a wind tunnel for testing and evaluation.

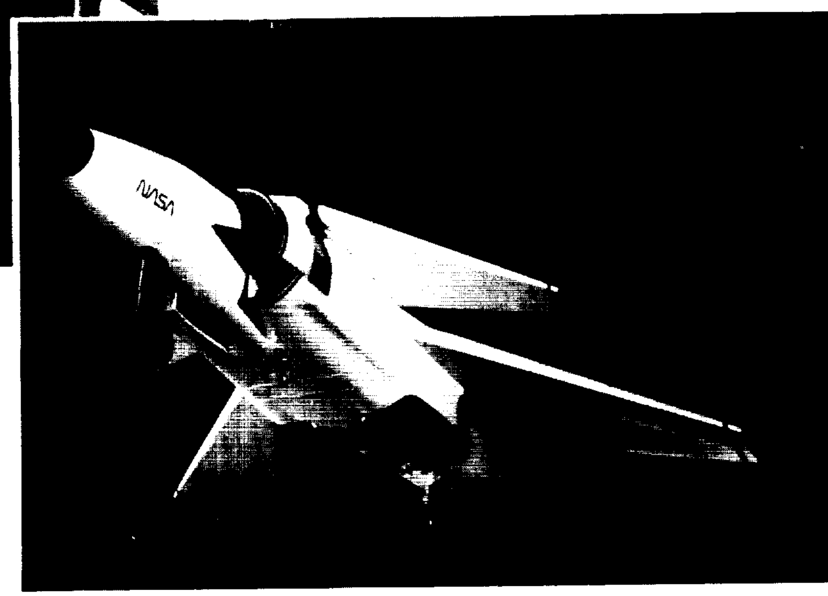
The advantages of using the CAD–CAM method are many. Engineers can test more designs before actually building the final product while eliminating the inaccuracies and lost time that go along with paperwork. Because there are fewer inaccuracies, the quality of the finished product is better. Since fewer prototypes must be built and tested, the time it takes to get a design out of the idea phase and into production is shortened. All of these advantages work to lower the cost of research.

Another way computers assist the design and development process is in scheduling and planning. Computerized project management helps the Engineering Directorate at Lewis keep track of the hundreds of projects it supervises. Project management involves determining how many people-hours are needed to complete a project, what resources are needed, and the best steps to follow. Small projects must sometimes be completed by a given date so that larger projects can keep moving ahead on time and at cost. Project management helps supervisors stay on top of who is working on what and when it must be completed.

The importance of scheduling is obvious when one considers designing experiment packages to be carried into space aboard the space shuttle. Shuttle launches are scheduled years in advance. If a research team is fortunate enough to be assigned space for a shuttle mission but fails to have their experiment package ready by launch time, they lose their opportunity and may have to wait years for another chance to have their experiment carried into space.

Computer-Controlled Test Facilities

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



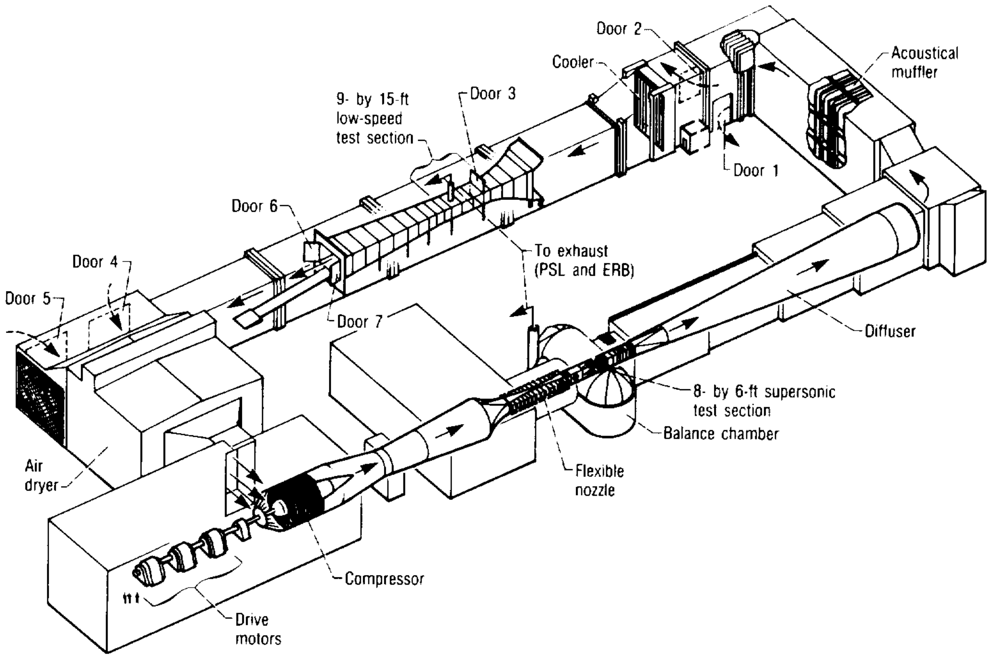
(Top) Control room for 8- by 6-Foot/9- by 15-Foot Wind Tunnel Complex. (Bottom) STOVL engine test in 9- by 15-Foot Wind Tunnel.

Computer testing in one of Lewis' wind tunnels is a critical phase of the design process.

The 8- by 6-Foot/9- by 15-Foot Wind Tunnel Complex is composed of two test sections. Each provides actual flight-like conditions for testing aerodynamic models. The 8- by 6-foot supersonic test section is 8 feet high, 6 feet wide, and 23 feet long. The airspeed in this section can be set anywhere from 230 mph (Mach 0.36) to 1320 mph (Mach 2). The 9- by 15-foot low-speed test section is 9 feet high, 15 feet wide, and 22 feet long. The airspeed in this section can be anywhere from 30 mph to about 175 mph. Three electric drive motors rated at 87,000 horsepower drive a compressor with enough thrust to move 56,000 cubic feet of air per second. Propelling the air in the wind tunnel to supersonic speeds requires first turning the compressor blades at about 860 revolutions per minute. With the compressor at full power the walls inside the tunnel have to be flexed into a nozzle shape to get the air moving even faster. Bending the walls speeds up the flow of air in much the same way that putting a nozzle on a garden hose speeds up the flow of water. The greater the bend in the walls, the higher the airspeed.

Computer control plays an important role in flexing the wind tunnel walls. A 35-foot-long section of wall constructed of 1-inch-thick stainless steel must be flexed into a smooth curve accurate to within thousandths of an inch. This requires enormous power. The 28 hydraulically driven screw jacks that accomplish this have enough power to fold the walls, crease them, and seriously damage them if the jacks are not precisely controlled.

Wind tunnel operators use a Westinghouse microprocessor-based control system to regulate the wind tunnel walls; to manage and acquire experimental data; to monitor and report on tunnel temperature, air pressure, and humidity; and to handle all numerical calculations. The system also has a historical retrieval unit that records events in the tunnel so that scientists can later review what was happening at various phases of an experiment.



8- by 6-Foot/9- by 15-Foot Wind Tunnel Complex. For scale, note the tiny human figures by the drive motors.

Two master consoles equipped with touch-sensitive color graphics displays—one for the 8- by 6-foot test section and one for the 9- by 15-foot test section—report tunnel conditions to the operators. Six distributed processing units (DPU's), each having specific control tasks assigned to it, communicate with one another through fiber optic cable. If one fails, a backup controller running a duplicate program takes over. DPU's are programmed from the control room.

During a wind tunnel test, operators view the test model on a television screen. The equipment used for each model and test is slightly different. Almost every model test requires some sort of pressure-measuring equipment. For some applications a computer is used to control a probe that steps through different data acquisition points along a model to get a pressure profile. Starting at one end, it reports readings to the Escort system. After Escort acknowledges that it has received data, which usually takes a second or two, the computer moves the probe to the next point.

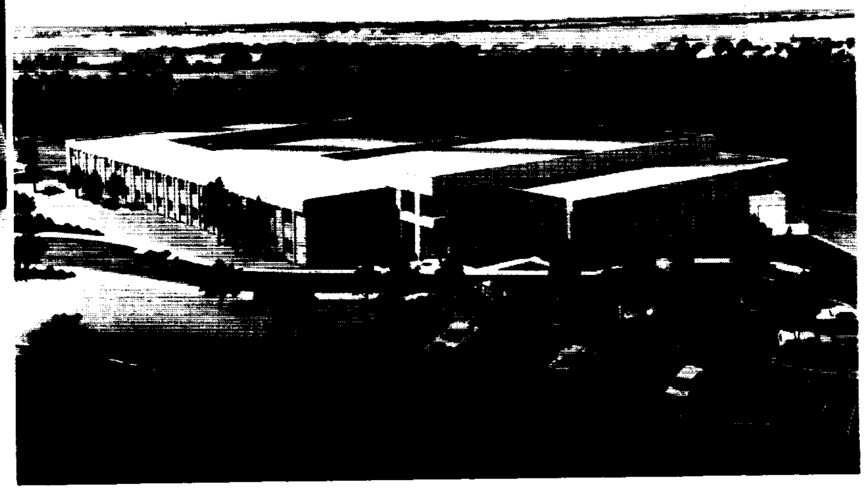
In the past the operation of the wind tunnel relied heavily on human judgment. Although human judgment and experience are still critical factors, decisions are now based on instantaneous information that was not available before computer control. An illustration of this is the way computers are used to control the shock waves during supersonic tests.

Shock waves develop when the airflow changes from subsonic to supersonic and back again. This usually occurs near the restriction of the tunnel walls. Because the shock wave has enough energy to crumple ⅛-inch-thick steel, it is important to keep the shock wave away from the model being tested. As the airspeed approaches supersonic, the shock wave forms and moves down the length of the tunnel's test section. As the airspeed is decreased, the shock wave moves back again. Computer-controlled shock doors help direct the location of the shock wave.

Shock wave control is critical during an emergency shutdown. If a tunnel must be shut down quickly, an operator has two options. The first is an emergency stop. This automatically shuts down the drive motors and completely opens the shock doors. It also takes control away from the computer, so that the model will probably be damaged by the shock wave. Before computer control this was an operator's only option.

The second option—now possible with computer control—is a fast stop. The fast stop shuts down the drive motors, but the computer retains control. It moves the shock doors to a safe position and holds them at that position until the computer senses that the shock wave has moved off. As soon as that happens, it opens the doors all the way and the shock wave dissipates.

Research Analysis Center



The Research Analysis Center, or the RAC Building as it is generally referred to at Lewis, was built in 1980 to serve as a centralized, shared, full-service computer facility.

Most of the people in the RAC Building work in the Computer Services Division. System engineers, analysts, programmers, technicians, and operators provide computer services to many locations within the 150-building Center. These services include developing programs; installing, operating, and maintaining computers; recording and processing data; supporting microcomputers; training; assisting in data security; and integrating data, voice, telephone, video, facsimile, Earth-bound, and satellite communications.

The RAC Building houses Lewis' major computers. Two Cray super-computers, two powerful Amdahl mainframes, numerous VAX minicomputers operating together in "clusters," an Alliant mainframe with multiple processors, and a large variety of special computer systems used in processing research data from all over the Center are located in the RAC Building's central computer room. The central computer room occupies approximately 31,000 square feet of the RAC Building.

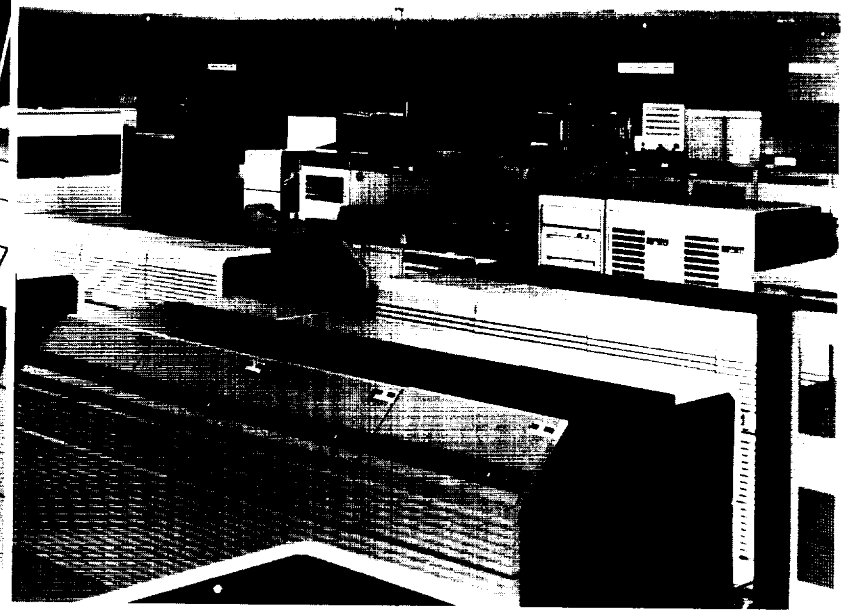
The RAC Building has many features that most office buildings do not. For instance, Lewis engineers added a unique heat recovery system. Because computers use so much electric power, they normally produce a great deal of heat. This heat is most often vented out by cooling fans and wasted. In the RAC Building this heat is collected and used to warm office space. Another interesting feature is the central computer room's backup power supply. Should the normal flow of electric power fail, the backup system would take over, providing power stored in banks of battery cells.

The RAC Building is also the control center for communications networks, such as the Lewis Information Network (LINK) and the Program Support Communications Network (PSCN). The LINK is the means by which users everywhere at Lewis gain access to the computers in the RAC Building. This Centerwide cable network simultaneously carries computer data, four video channels, and data from test facilities. PSCN is Lewis' connection to computer systems at other NASA centers across the country.

Completed in 1989, a $10 million RAC Building expansion added 5500 square feet, or 25 percent more computer room space, on the first floor and another 5500 square feet of computer room space on the second floor. The focal point of the expansion is its two-story atrium lobby. Four new areas for the User Services Branch have been opened. These include a library, a workstation support center, a problem management office, and a training facility. Twenty-eight offices have also been added. Large support areas are subdivided with movable walls and can be configured either as offices or as computer room space. In the expanded computer room new systems can be tested alongside the systems they are replacing, thereby eliminating the need to remove a computer before its replacement can be installed. When users are moved to the new systems, their schedules are not interrupted.

The design of the RAC Building expansion allows for the addition of a third and fourth story should they be required in the future.

Major Systems in the RAC Building



Although computers can be found throughout the 150-building Center, the most powerful computer systems are located where they can be shared by everyone—in the central computer room of the RAC Building.

Lewis' major systems include two Cray supercomputers, an Alliant parallel processor, two Amdahl mainframes, an IBM 3090 vector processor, a Convex C220 with two processors, and several VAX cluster systems. The central computer room also holds data acquisition equipment that gathers results from experiments being conducted all over the Center. Authorized users gain access to these computers through their terminals and the Lewis Information Network (LINK)—a centerwide cable network that carries data as well as video transmissions.

The Crays, with their extremely high-speed multiple processors, can run programs that might take hours to run on another computer. The Crays are so fast that even the speed of the electrons in their circuits is critical. For this reason the designers shortened the lengths of wire in the internal circuitry. This accounts for the Crays' unique cylindrical shape.

Work is kept flowing efficiently into the Cray by using several other computers as "front end" staging areas. Jobs waiting to be run on the Cray are automatically assigned a run time during the day, at night, or on the weekend, depending on the amount of memory and processing time required. At its assigned time each front-end computer channels its data directly to the Cray. When the jobs are completed, the Cray offloads the results back to the front-end computers. The Alliant computer employs a method of computing called parallel processing in which eight high-speed processors work together to solve complex problems. The Alliant is primarily used by Lewis researchers to explore parallel processing.

Two Amdahl systems are shared by hundreds of computer users at Lewis. The Amdahl's operating system makes it possible for all these users to share a single computer without interfering in one another's work. Both scientific and business programs are installed on these systems.

The central computer room also houses two VAX clusters. One is dedicated to various scientific and engineering applications. The other hosts the Lewis Information Management System (LIMS). LIMS and the LINK makes it possible for any person with a LIMS workstation and the proper authorizations to connect to any of the major computer systems at Lewis. Clustering (or integrating) these computers is a way to combine and share their processing and storage capabilities. As the need for computing power increases, more VAX systems can be added to the cluster.